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Li, Chi-Min; Wu, Jia-Chyi; and Tang, I-Tseng (2007) "AN ANALYTIC ANALYSIS OF W-CDMA SMART ANTENNAS BEAMFORMING USING COMPLEX CONJUGATE AND DOA METHODS," *Journal of Marine Science and Technology*. Vol. 15: Iss. 4, Article 3.

DOI: 10.51400/2709-6998.2045

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### Acknowledgements

This research work was supported by the National Science Council of the Republic of China under the Grant number NSC 95-2221-E-019-018.

# AN ANALYTIC ANALYSIS OF W-CDMA SMART ANTENNAS BEAMFORMING USING COMPLEX CONJUGATE AND DOA METHODS

Chi-Min Li\*, Jia-Chyi Wu\*, and I-Tseng Tang\*\*

Key words: W-CDMA, complex conjugate, direction-of-arrival.

## ABSTRACT

Wideband Code Division Multiple Access (W-CDMA) adopts the smart antenna techniques to increase the signal-to-interference-noise ratio (SINR) and system capacity. In this paper, we statistically derive analytic results to prove the SINR performance for the two commonly used CC and DOA beamforming methods. Results show the both methods will have the same mean SINR performance and CC method will be more robust than the DOA method.

## INTRODUCTION

As the rapid growth of utilization for modern terrestrial radio system, more and more demands on system capacity and throughput are required to satisfy various kind of wireless applications [1, 5, 9]. Wideband Code Division Multiple Access (W-CDMA), also known as 3G system, adopts the smart antenna techniques to increase the signal-to-interference-noise ratio (SINR) and system capacity [2]. Based on the different adaptation methods, smart antenna can be divided into two categories, i.e., switched beam method and adaptive array. A switched beam smart antenna uses a predetermined high-gain beamwidth antenna for signal reception or transmission [7]. Intuitively, switched beam array performs worse than the adaptive array, yet it has the advantage that hardware implementation is more easier compared with the adaptive array method. Adaptive antennas form the main beam to the desired user and null the undesired interferences by an adjustable weighting set. This weightings set can be obtained via some criteria such as MMSE, LMS, RLS..etc [3]. Among these methods, Complex Conjugate (CC) and Direc-

tion-of-Arrival (DOA) methods are two widely used methods due to its simplicity and fast weightings calculation capability [4].

Recently, some performance results for the CC and DOA beamforming methods were reported. Li and Liu [6] stated that the CC and DOA have almost the same SINR performance in the uplink channel based only on computer simulations. And the CC method will have 1dB SINR degradation worse than the DOA method if the weightings estimated in the uplink are applied to the downlink channel. In this paper, we have established analytic SINR evaluation equations for the CC and DOA methods in a W-CDMA smart antenna. Besides, performance and robustness analyses of the two methods under different channel scenarios are given for further verifications. Two different channel scenarios are considered, one is in perfect channel estimation condition and the other is estimated with errors. According to the 3GPP specifications [8], channel attenuation and time-of-arrival (TOA) can be estimated by the Match Filter (MF) and known pilot symbols in the dedicated physical control channel (DPCCH) of the WCDMA system in the uplink transmission. With these parameters, performance analysis of different beamforming techniques can be evaluated.

The paper is organized as follow: Section II gives a brief review of the CC and DOA methods and derives analytic SINR results for both methods. The derivatives consider fading channel with Additive-White-Gaussian-Noise (AWGN) and Multiple Access Interference (MAI). In Section III, simulation results on the derived results will be given to verify their performances. We consider both the Line-of-Sight (LOS) and Non-LOS (NLOS) wireless channel in the simulation. Finally, some conclusions are given in Section IV for this paper.

## SYSTEM DESCRIPTIONS

In a W-CDMA system, a  $M$ -elements antenna array with  $P$ -fingers Rake Receiver that receives the  $0^{\text{th}}$  user's signal can be illustrated as

where  $w_{p,m,k}$  is the attenuation compensation

Paper Submitted 09/19/06, Accepted 12/14/06. Author for Correspondence: Chi-Min Li. E-mail: cml@mail.ntou.edu.tw

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weighting at time  $\tau_{p,m,k}$ .  $\tau_{p,m,k}$  is the time-of-arrival (TOA) of the  $p$ th multipath at the  $m$ th receiving antenna for the  $k$ th user. In general, SINR of the received signal can be increased by the properly chosen weightings  $w_{p,m,k}$  of each antenna. Two simple and efficient weighting adjust methods, the CC and DOA are briefly reviewed as follow.

**1. CC (complex conjugate) beamforming**

The CC method uses the estimated TOA  $\tau_j$  of the desired signal to predict the delay profile attenuation  $\hat{h}$  of each antenna element. Once  $\hat{h}$  be estimated, we can use Eq.(1) to determine the weightings of each antenna.

$$w_{ij} = \hat{h}_i^*(\tau_j) \tag{1}$$

where  $i = 1 \sim M, j = 1 \sim P$ . the weightings

Intuitively, the CC method multiplies the complex conjugate of the DPCCH estimation to compensate the channel attenuation and maximizes the SINR. Therefore, receiver sums up the compensated signals of each element to detect the transmitted symbol. It has the advantage of simple computation and operates like the Maximum Ratio Combining (MRC) method which is the optimal diversity combining technique.

**2. DOA (direction-of-arrival) beamforming**

Compared with the CC method, DOA method uses another estimated signal parameter: DOA, to decide the

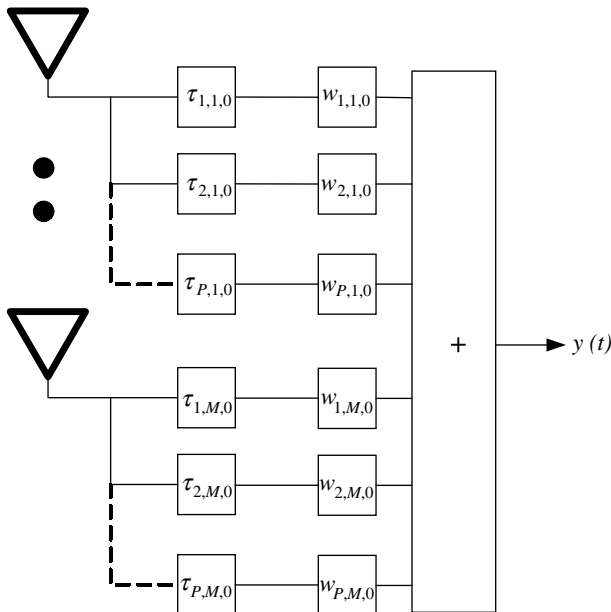


Fig. 1. A -elements antenna array with-fingers rake receiver.

weightings  $w_{ij}$ . Due to the phase relation of the received signal and the geometry of antenna array (a linear equal space antenna array with half-wavelength separation is considered in this paper),  $w_{ij}$  can be determined by Eq.(2)

$$w_{ij} = w_{ij}^* e^{-j2\pi(i-1)(d/\lambda)\cos\theta_j} \tag{2}$$

where  $i = 1 \sim M, j = 1 \sim P$ .  $w_{1j} = \hat{h}_1(\tau_j)^*$ ,  $\lambda$  is the wavelength,  $d$  is the antenna separation.

In the DOA method, channel compensation can be achieved by the phase relation of the incident signals. Once the attenuated signals are compensated, signals of different antennas are summed up to decide the transmitted symbol.

Besides, a P-paths time-invariant channel for the  $k$ th user at the  $m$ th receiving antenna can be modeled as

$$h_{m,k}(t) = \sum_{p=0}^{P-1} h_{p,m,k} \delta(t - \tau_{p,m,k}) \tag{3}$$

Let the DPCCH and dedicated physical data channel (DPDCH) of the desired user have the spreading factor  $F_c$  and  $F_d$  respectively. Assume the 0<sup>th</sup> user is the desired signal for processing, the  $p$ th finger output voltages  $y_{c,p,m}, y_{d,p,m}$  of the matched filter (MF) for the DPCCH and DPDCH can be expressed separately as

$$\begin{aligned} y_{c,p,m} &= F_c h_{p,m,0} + i_{c,p,m} + n_{c,p,m} \\ &= F_c h_{p,m,0} + \eta_{c,p,m} \end{aligned} \tag{4}$$

$$\begin{aligned} y_{d,p,m} &= b F_d h_{p,m,0} + i_{d,p,m} + n_{d,p,m} \\ &= b F_d h_{p,m,0} + \eta_{d,p,m} \end{aligned} \tag{5}$$

where  $h_{p,m,0}$  is the  $p$ th multipath attenuation for the desired user,  $i_{c,p,m}, i_{d,p,m}$  and  $n_{c,p,m}, n_{d,p,m}$  are the  $p$ th multiple access interference (MAI) and AWGN thermal noise at the DPCCH and DPDCH channel at the  $m$ -th receiving antenna. The statistical properties of these random variables are

$$\begin{aligned} E \left\{ |i_{c,p,m}|^2 \right\} &= F_c (K - 1) \\ E \left\{ |n_{c,p,m}|^2 \right\} &= F_c \sigma_n^2 \\ E \left\{ |\eta_{c,p,m}|^2 \right\} &= E \left\{ |i_{c,p,m}|^2 \right\} + E \left\{ |n_{c,p,m}|^2 \right\} \\ &= F_c [(K - 1) + \sigma_n^2] \end{aligned} \tag{6}$$

$$\begin{aligned}
 E\left\{\left|i_{d,p,m}\right|^2\right\} &= F_d(K-1) \\
 E\left\{\left|n_{d,p,m}\right|^2\right\} &= F_d\sigma_n^2 \\
 E\left\{\left|\eta_{d,p,m}\right|^2\right\} &= E\left\{\left|i_{d,p,m}\right|^2\right\} + E\left\{\left|n_{d,p,m}\right|^2\right\} \\
 &= F_d[(K-1) + \sigma_n^2] \tag{7}
 \end{aligned}$$

where  $K$  is the total number of users.

Assume that the DPCCH and DPDCH have the same channel characteristics during transmission, by using the CC method to combine the RAKE finger outputs, the output voltage of the DPDCH smart antenna receiver  $V_{out}$  is given by

$$V_{out} = \sum_{m=1}^M \sum_{p=1}^P y_{d,p,m} y_{c,p,m}^* \tag{8}$$

Suppose that the DPCCH can estimate the channel perfectly, i.e.,  $\eta_{c,p,m} = i_{c,p,m} + n_{c,p,m} = 0$ , we have

$$\begin{aligned}
 V_{out} &= \sum_{m=1}^M \sum_{p=1}^P (bF_d h_{p,m,0} + \eta_{d,p,m}) F_c h_{p,m,0}^* \\
 &= bF_d F_c \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,m,0}^* \tag{9}
 \end{aligned}$$

The SINR for the P-fingers CC RAKE receiver at the DPDCH is

$$\begin{aligned}
 SINR_{Perfect}^P &= \frac{F_d^2 F_c^2 \left[ \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 \right]^2}{E \left\{ \left[ \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,m,0}^* \right]^2 \right\}} \\
 &= \frac{F_d \left( \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 \right)}{(K-1) + \sigma_n^2} \tag{10}
 \end{aligned}$$

where we have assumed that  $E\{\eta_{d,p,m} \eta_{c,p,m}^*\} = 0$  and  $E\{\eta_{d,p,m} \eta_{c,p',m}^*\} = 0$  for  $p \neq p'$ . Note that if we assume that  $h_{p,m,0}$  is a complex Gaussian random variable with zero mean and variance  $2\sigma^2$ , then,  $|h_{p,m,0}|^2$  will be a Chi-square distributed random variable and  $\sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2$  will also be a Chi-square distributed random variable with mean  $2MP\sigma^2$  and variance  $4MP\sigma^4$ . That is, the

received SINR of the CC method can be modeled as a Chi-square distributed random variable with mean  $2AMP\sigma^2$ , variance  $4A^2MP\sigma^4$  according to Eq.(10), where  $A = F_d/(K-1) + \sigma_n^2$ .

If the DPCCH is unable to estimate the channel perfectly, i.e.,  $\eta_{c,p,m} = i_{c,p,m} + n_{c,p,m} \neq 0$ , we find that the output voltage of the DPDCH RAKE receive  $V_{out}$  is

$$\begin{aligned}
 V_{out} &= \sum_{m=1}^M \sum_{p=1}^P \left( bF_d h_{p,m,0} + \eta_{d,p,m} \right) \left( F_c h_{p,m,0}^* + \eta_{c,p,m}^* \right) \\
 &= bF_d F_c \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + bF_d \sum_{m=1}^M \sum_{p=1}^P h_{p,m,0} \eta_{c,p,m}^* \\
 &\quad + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,m,0}^* + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} \eta_{c,p,m}^* \tag{11}
 \end{aligned}$$

The SINR for the P-fingers CC RAKE receiver at the DPDCH is given by

$$\begin{aligned}
 SINR_{Interference}^P &= \frac{F_d^2 F_c^2 \left[ \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 \right]^2}{E \left\{ \left[ bF_d \sum_{m=1}^M \sum_{p=1}^P h_{p,m,0} \eta_{c,p,m}^* + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,m,0}^* + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} \eta_{c,p,m}^* \right]^2 \right\}} \\
 &= \frac{F_d F_c \left[ \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 \right]^2}{[(K-1) + \sigma_n^2] \left\{ (F_d + F_c) \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + PM[(K-1) + \sigma_n^2] \right\}} \tag{12}
 \end{aligned}$$

where we have assumed that  $E\{\eta_{d,p} \eta_{d,p'}^*\} = 0$  for  $p \neq p'$ ,  $E\{\eta_{c,p} \eta_{c,p'}^*\} = 0$  for  $p \neq p'$  and  $E\{\eta_{c,p} \eta_{d,p'}^*\} = 0$  for all  $p, p'$ . The performance degradation due to the channel estimation error by using the CC method can therefore be expressed as

$$\begin{aligned}
 Degradation &= \frac{SINR_{Interference}^P}{SINR_{Perfect}^P} \\
 &= \frac{F_c \left[ \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 \right]}{\left\{ (F_d + F_c) \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + PM[(K-1) + \sigma_n^2] \right\}} \tag{13}
 \end{aligned}$$

Considering another case, if we use the DOA method to determine the weightings, the output voltage of the DPDCH smart antenna receiver  $V_{out}$  is given by

$$V_{out} = \sum_{m=1}^M \sum_{p=1}^P y_{d,p,m} y_{c,p,1}^* e^{-j(m-1)\pi \cos \theta_p} \quad (14)$$

where  $\theta_p$  is the AOA of the p-th multipath of the desired user. Suppose that the DPCCH can estimate the channel perfectly, i.e.,  $\eta_{c,p,m} = i_{c,p,m} + n_{c,p,m} = 0$ , we have

$$\begin{aligned} V_{out} &= \sum_{m=1}^M \sum_{p=1}^P \left( bF_d h_{p,m,0} + \eta_{d,p,m} \right) \left( F_c h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} \right) \\ &= bF_d F_c \sum_{m=1}^M \sum_{p=1}^P h_{p,m,0} h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} \\ &\quad + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} \end{aligned} \quad (15)$$

The SINR for the P-fingers DOA smart antenna receiver at the DPDCH is

$$\begin{aligned} SINR_{Perfect}^P &= \frac{F_d^2 F_c^2 \left[ \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2 \right]}{E \left\{ \left| \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} \right|^2 \right\}} \\ &= \frac{F_d^2 F_c^2 \left[ \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2 \right]}{F_d F_c^2 \{ (K-1) + \sigma_n^2 \} \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)} \\ &= \frac{F_d \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)}{\{ (K-1) + \sigma_n^2 \}} \end{aligned} \quad (16)$$

where we have assumed that  $E\{\eta_{d,p,m}\eta_{c,p',m}^*\} = 0$  and  $E\{\eta_{d,p,m}\eta_{d,p',m}^*\} = 0$  for  $p \neq p'$ . Note that if we assume that  $h_{p,1,0}$  is a complex Gaussian random variable with zero mean and variance  $2\sigma^2$ , then, the received SINR of the DOA method can be described as a Chi-square distributed random variable with mean  $2AMP\sigma^2$  and variance  $4A^2M^2P\sigma^4$ .

If the DPCCH is unable to estimate the channel perfectly, i.e.,  $\eta_{c,p,m} = i_{c,p,m} + n_{c,p,m} \neq 0$ , the output voltage of the DPDCH smart antenna receiver  $V_{out}$  is given by

$$\begin{aligned} V_{out} &= \sum_{m=1}^M \sum_{p=1}^P \left( bF_d h_{p,m,0} + \eta_{d,p,m} \right) \left( F_c h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} + \eta_{c,p,m}^* \right) \\ &= bF_d F_c M \sum_{p=1}^P |h_{p,1,0}|^2 + bF_d \sum_{m=1}^M \sum_{p=1}^P h_{p,m,0} \eta_{c,p,m}^* \\ &\quad + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} \eta_{c,p,m}^* \end{aligned} \quad (17)$$

The SINR for the P-fingers DOA RAKE receiver at the DPDCH is given by

$$\begin{aligned} SINR_{Interference}^P &= \frac{F_d^2 F_c^2 \left[ \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2 \right]}{E \left\{ \left| bF_d \sum_{m=1}^M \sum_{p=1}^P h_{p,m,0} \eta_{c,p,m}^* + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} F_c h_{p,1,0}^* e^{-j(m-1)\pi \cos \theta_p} + \sum_{m=1}^M \sum_{p=1}^P \eta_{d,p,m} \eta_{c,p,m}^* \right|^2 \right\}} \\ &= \frac{F_d^2 F_c^2 \left[ \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2 \right]}{F_d^2 F_c \{ (K-1) + \sigma_n^2 \} \left[ \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + F_c^2 F_d \{ (K-1) + \sigma_n^2 \} \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right) + F_c F_d PM \{ (K-1) + \sigma_n^2 \} \right]} \\ &= \frac{F_d F_c \left[ \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2 \right]}{\{ (K-1) + \sigma_n^2 \} \left\{ F_d \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + F_c M \sum_{p=1}^P |h_{p,1,0}|^2 + PM \{ (K-1) + \sigma_n^2 \} \right\}} \end{aligned} \quad (18)$$

where we have assumed that  $E\{\eta_{d,p,m}\eta_{c,p',m}^*\} = 0$  for  $p \neq p'$ ,  $E\{\eta_{c,p,m}\eta_{c,p',m}^*\} = 0$  for  $p \neq p'$  and  $E\{\eta_{c,p,m}\eta_{d,p',m}^*\} = 0$  for all  $p \neq p'$ . The performance degradation due to the channel estimation error by using the DOA method can therefore be expressed as

$$Degradation = \frac{SINR_{Interference}^P}{SINR_{Perfect}^P}$$

$$\begin{aligned}
 & \frac{F_d F_c \left[ \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2 \right]}{\left[ (K-1) + \sigma_n^2 \right] \left\{ F_d \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + F_c M \sum_{p=1}^P |h_{p,1,0}|^2 + PM \left[ (K-1) + \sigma_n^2 \right] \right\}} \\
 &= \frac{F_d \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2}{\left[ (K-1) + \sigma_n^2 \right]} \\
 &= \frac{F_c \left( M \sum_{p=1}^P |h_{p,1,0}|^2 \right)^2}{F_d \sum_{m=1}^M \sum_{p=1}^P |h_{p,m,0}|^2 + F_c M \sum_{p=1}^P |h_{p,1,0}|^2 + PM \left[ (K-1) + \sigma_n^2 \right]}
 \end{aligned} \tag{19}$$

An interesting result can be observed if we look into Eq.(10) and Eq.(16) which are the SINR performance of the CC and DOA methods respectively under the perfect channel estimation scenario. Table 1 lists the summary of the derived results.

Table 1 reveals that both the CC and DOA methods will have the same mean SINR performance statistically. And the SINR will be increase if we increase either  $M$  (antenna number) or  $P$  (RAKE finger number) at the receiver. However, the CC method has less SINR variation ( $4AMP\sigma^4$  in the CC case versus  $4AM^2P\sigma^4$  in the DOA case) compared with the DOA method. It implies that the output SINR of the CC method will be more stable than the DOA method. This result comes from the assumption of the DOA method that the incident signals received by the array differ only in phase. And the phase difference is linear proportional to the antenna spacing. Same phenomenon occurs in Eq.(12) and Eq.(18) for the CC and DOA method when the channel estimation contains errors from the MAI and AWGN.

**SIMULATIONS**

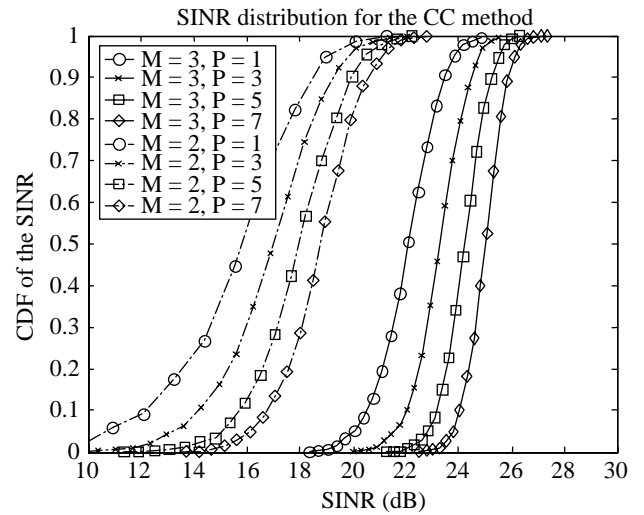
In this section, we simulate the derived results to analyze the performance of the CC and DOA techniques. We assume that perfect power control of the system can

**Table 1. Summary of the CC and DOA Performance**

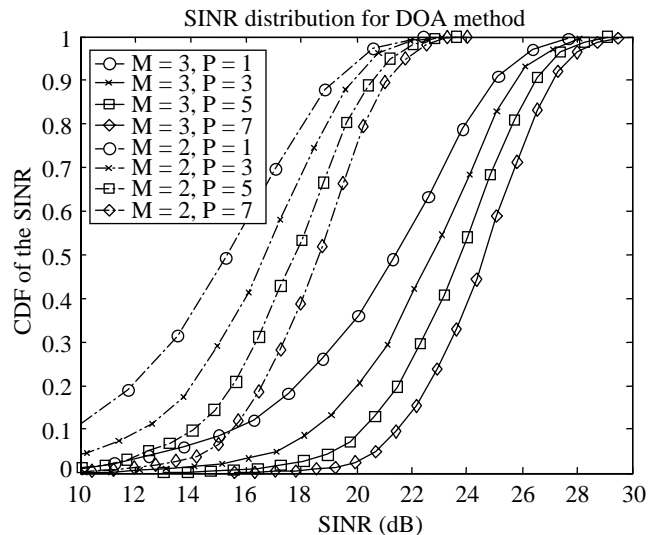
	CC	DOA
Distribution of SINR	Chi-Square distributed	Chi-Square distributed
Expectation	$2AMP\sigma^2$	$2AMP\sigma^2$
Variance	$4A^2MP\sigma^4$	$4A^2M^2P\sigma^4$

be achieved and all multipaths attenuations are independent and identically distributed. Assuming there are 20 active users in the coverage of a base station, the serving base station adopts smart antennas with  $M$  receiving elements for receiving. Each receiving antenna consists of a  $P$ -fingers RAKE receiver to form the coherent output for detection. The spreading factors (SF) set to 64 in the DPDCH channel and 256 in the DPCCH channel for all active users. Besides,  $\sigma_n^2 = \sigma = 1$  and  $|h_{p,m,k}|$  are either Rayleigh or Ricean fading depends on the channel environment. Both the line-of-sight (LOS) and the non-line-of-sight (NLOS) cases are considered in this simulation.

Figure 2 and Figure 3 are the estimated cumulative



**Fig. 2. CDF of the SINR using CC method under perfect channel estimation.**



**Fig. 3. CDF of the SINR using DOA method under perfect channel estimation.**

distribution function (CDF) results of the SINR if the channels are randomly generated 1000 times under the perfect channel estimation case. The number of receiving antennas  $M$  could be either 2 or 8 while the finger number  $P$  could be 1, 3, 5, 7. In LOS case, Ricean factor of the channel is set to 3.52 dB. Comparing Figure 2 with Figure 3, we notice that both the CC and DOA methods have approximately the same mean SINR performance. For example, for  $M = 8, P = 1$  in Figure 2, SINR of the CC has approximately 21 dB and ranges from 19 dB to 25 dB, while for  $M = 8, P = 1$  in Figure 3, SINR of the DOA has approximately the same 21 dB, yet, its SINR ranges from 10 dB to 28 dB. That is, the

CC method is more robust because its output SINR has less variation. This result confirms our pervious prediction for the two methods.

Figure 4 and Figure 5 are the estimated CDF results of the SINR if the channels are not perfect channel estimated. We can note that same mean SINR performance for both the CC and DOA methods and the CC method is more robust than the DOA method even in the imperfect channel estimation case.

Similar simulation results for the NLOS case are illustrated from Figure 6 to Figure 9. Except for the Ricean factor ( $-\infty$  dB for NLOS), all parameters are the same as in the LOS case. Table 2 lists the detail

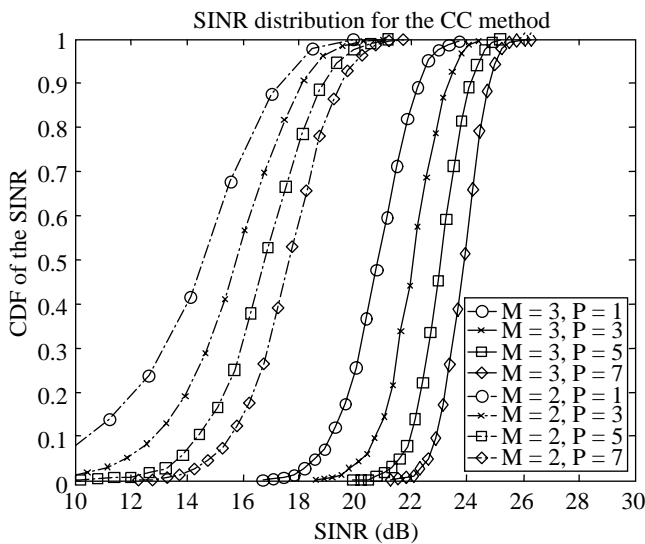


Fig. 4. CDF of the SINR using CC method under imperfect channel estimation.

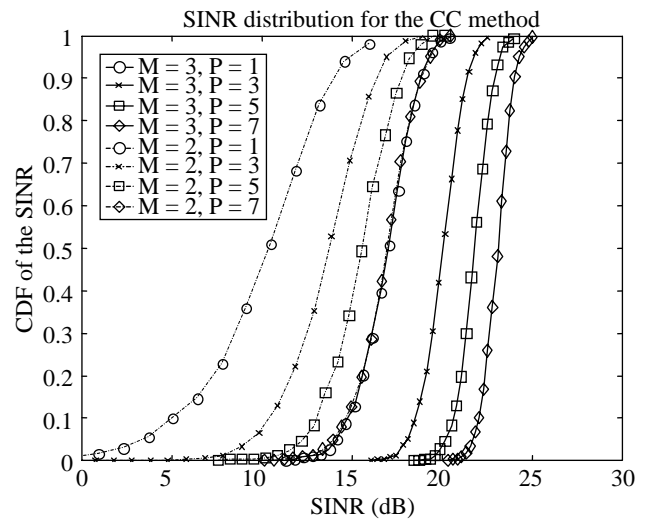


Fig. 6. CDF of the SINR using CC method under perfect channel estimation in NLOS Case.

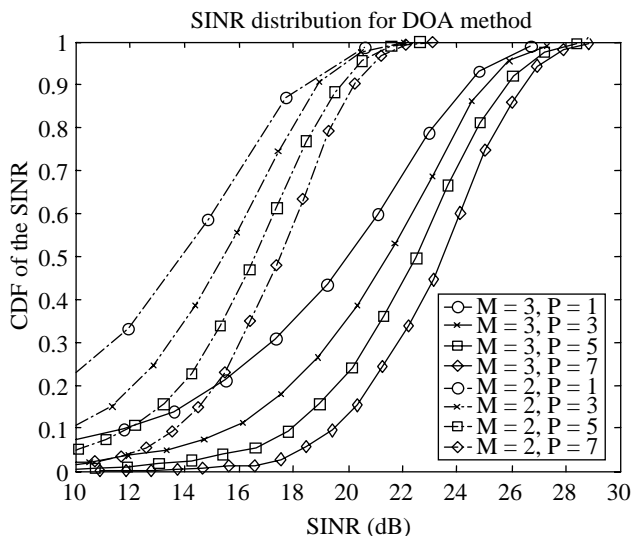


Fig. 5. CDF of the SINR using DOA method under imperfect channel estimation.

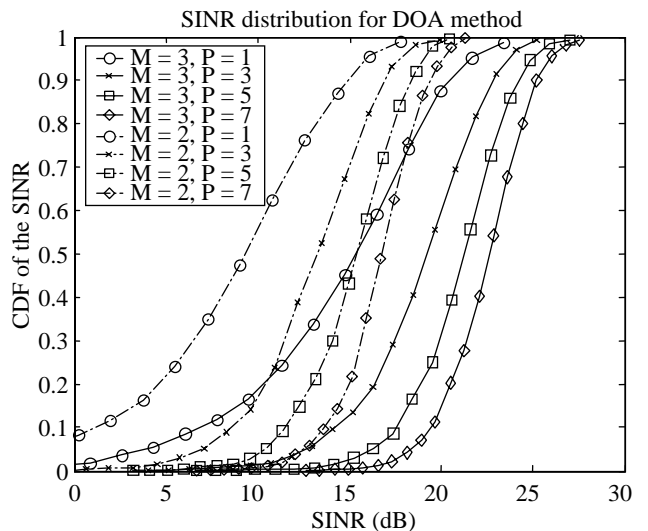
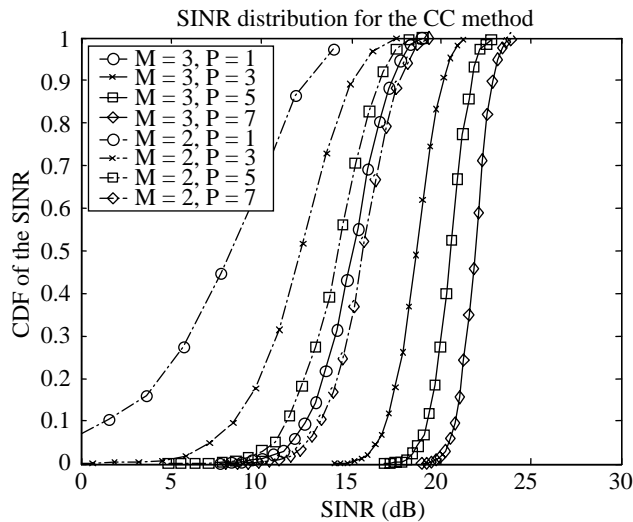


Fig. 7. CDF of the SINR using DOA method under perfect channel estimation in NLOS case.

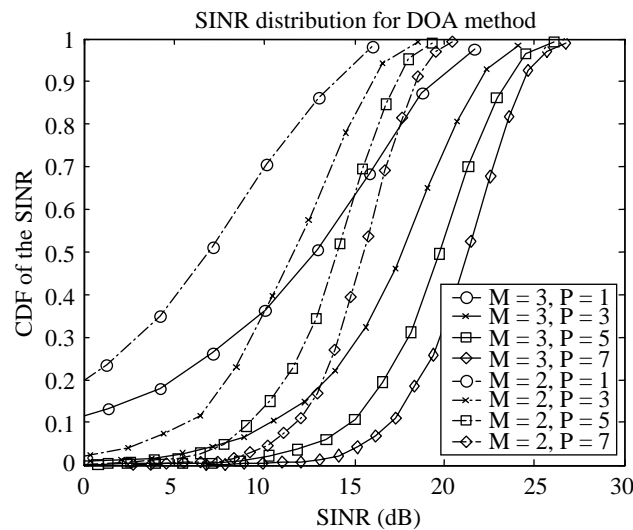


**Table 2. Numerical SINR Results for the CC and DOA Method**

Mean/Range (dB)	CC	DOA
M = 2, P = 1	10 dB/(0 ~ 16 dB)	9.5dB/(-2 ~ 18 dB)
M = 2, P = 3	13 dB/(7 ~ 18 dB)	13dB/(0 ~ 19 dB)
M = 8, P = 1	16 dB/(10 ~ 18 dB)	16dB/(0 ~ 22 dB)
M = 8, P = 3	18 dB/(16 ~ 21 dB)	18dB/(5 ~ 23 dB)



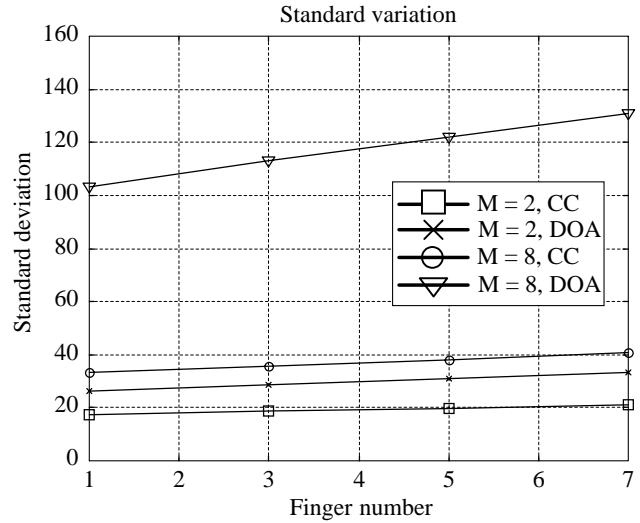
**Fig. 8. CDF of the SINR using CC method under imperfect channel estimation in NLOS case.**



**Fig. 9. CDF of the SINR using DOA method under imperfect channel estimation in NLOS case.**

numerical expectations and distributions for the CC and DOA SINR performance in Figure 6 and Figure 7.

Figure 10 describes the relations of the calculated



**Fig. 10. Variations for the CC and DOA method.**

standard deviation versus  $M$  and  $P$  under the LOS channel. Results show that the SINR of the CC method has less variation than the DOA method for the same  $M$  and  $P$ . Besides, SINR variation increases linear proportional to  $M$  in the CC method and approximately  $M^2$  in the DOA method.

**CONCLUSIONS**

In this paper, we established analytic SINR evaluation equations of the CC and DOA methods in a W-CDMA smart antenna. Performance and robustness analyses of the two methods under perfect and imperfect channel estimation scenarios are also derived. Results show that both methods have the same mean SINR performance where the CC method presents more robust than the DOA method under all simulated scenarios.

**ACKNOWLEDGMENTS**

This research work was supported by the National Science Council of the Republic of China under the Grant number NSC 95-2221-E-019-018.

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